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PULSE FREQUENCY MODULATION

code-none
NASA TMX56420

Telemetry implies the measurement of a quantity from a location removed from the site of the event. The telemetry transmission link may be via light, sound or electromagnetic radio waves. In any of these modes of transmission, attenuation of the data signal is a serious factor. Inherent with this attenuation, interference in many forms is usually present, which perturbs the signal information causing misinterpretation errors by the receiver. In order to minimize the effects of the various undesirable perturbations, encoding of the data at the source is required. The maximum immunization to noise is governed by Shannon's channel capacity theorem relating the minimum data recovery error to data bandwidth, noise power and signal power (reference 1). Basically the problem then is to utilize a system which approaches the maximum transmission link capacity and which allows a reduction in transmitter power.

Since it is usually both undesirable and impractical to send data from each signal source over an independent transmission link, the process of multiplexing is used. Multiplexing is the sending of more than one source (or channel) of information over a single link. This intermixing process may be performed either in frequency or time. In frequency division multiplexing each channel of information is assigned its own band of frequencies (or subcarrier) and the linearly added subcarriers then modulate the transmitted carrier. The resulting modulation is known as FM-FM, FM-AM or FM-PM, where the last two letters in the modulation nomenclature denote the modulation technique; e.g., FM is frequency modulation, AM is

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amplitude modulation and PM is phase modulation.

Frequency division multiplexed telemetry is standardly used with frequency modulation to gain the inherent signal to noise improvement this technique offers over amplitude modulation. However frequency modulation has several disadvantages: first, the signal to noise ratio is only improved with wide carrier deviations (i.e., wide transmission bandwidth) and secondly, the well-known sharp thresholding phenomenon at low signal levels. FM-FM in itself has another disadvantage in that guard bands of frequency, in which no data is allowed, must exist between the subcarrier frequency bands in order to allow reliable recovery and deciphering of the data on the receiving end.

The second division of data transmission is time-division multiplexing. Time-division multiplexing is the sequential and periodic sampling (commutation) of a number of sources of data and the assembling of these samples into a serial data train. Each source is periodically assigned a finite time for transmission. Examples of time-division multiplexing are the various pulsed telemetry systems.

Developments in pulse modulation and pulse coded modulation lagged frequency modulation. Early work in this field led to pulse amplitude modulation-PAM; pulse position modulation-PPM; and pulse duration modulation-PDM. Needless to say any of these systems could use amplitude modulation, phase modulation, or frequency modulation as the transmission scheme. These systems however rely on the precise determination of pulse amplitude, position or duration, all of which are quantities hard to resolve in the presence of noise.

In the late 40's and early 50's, Shannon and Hamming performed studies which predicted that pulse coding would have error reducing properties and which produced practical schemes of coding to effect these properties (reference 2). This system is known as pulse code modulation - PCM.

With the criteria in mind of designing a telemetry system which minimizes the data recovery error and which is efficient and reliable, pulse-frequency-modulation - PFM - was developed. Pulse frequency modulation, with the advent of modern semiconductors and magnetic cores, has gained an advantage in low power requirements and long term hardware reliability.

A PFM signal consists of a series of time multiplexed sequential tone bursts of known pulse length. The frequency of the burst conveys the desired data information. Figure 1a shows the pulse pattern (or format) for a typical N.A.S.A. Goddard Space Flight Center PFM signal. If there are N channels (or sources) to be sampled then each channel would be associated with a separate frequency burst and the frequencies of these N bursts would represent the data of the sequentially sampled channels. In practice in the NASA/GSFC PFM system there are 16 channels with the first channel reserved for synchronization. Periodic data bursts must be reserved for synchronization data in order to identify the location of a particular data source in the tone burst train. A set of 16 channels is known as a frame, and 16 frames complete a telemetry sequence.

Figure 1b shows a complete telemetry sequence. The tone bursts are transmitted beginning with channel zero - frame zero and progressing in time through frame zero, then to frame one and so forth until a complete sequence has been telemetered. Each channel is divided into two parts. A data channel has equal data and blank times. The blank time is to allow the contiguous filter banks used on the receiving end to recover before the next data burst. This blank time (time of no modulation) is utilized on the ground to determine channel synchronization. Present satellites, notably the Interplanetary Explorer Series (IMP), have a known constant frequency tone burst, outside the data frequency band, in the blank portion of each channel for channel synchronization. Channel zero has a 3/4 channel wide burst for frame identification purposes. Every other channel zero has a known reference tone burst (marked sync in figure 1b) identifying the start of the frame. The channel zeros without a reference burst contain one of eight different frequencies representing a particular frame number: e.g., a tone representing octal 000 would mean frame 1. Thus both the start of each frame is marked as well as the number of the frame.

As with any pulse-coded system simplicity in transmission hardware is paid for in the magnitude of synchronization and decommutation equipment required at the processing terminal. With improvement in data synchronization techniques and hardware a greater proportion of the telemetry may be allocated for data transmission. The present state of the art allows the channel blanks, previously used for channel synchronization, to be utilized for data.

In PFM, both analog and digital data may be easily encoded. PCM suffers in that all data must be converted into digital form for transmission. Data signals are encoded in the NASA/GSFC PFM using pulsed oscillators. For analog data a subcarrier oscillator, whose output frequency is directly proportional to the analog voltage impressed at its input, is used. The linearity of the presently used analog oscillator is better than $\pm \frac{1}{2}$ percent over a 3:1 dynamic frequency range. Typically the long-term accuracy of measurement is within 1 percent. However, short-term precision measurements can be made to 1/10 percent (reference 3).

Digital signals are telemetered by combining binary bits and presenting these as a single digit of a higher order base. The present state of the art allows encoding of three bits into one digit to the base eight, or four bits into one digit to the base sixteen. For example in the base eight system one of eight frequencies is transmitted in pulse tone form, representing one of eight octal digital numbers. Similarly in the base sixteen system one of sixteen tone bursts would be transmitted. This is accomplished with a pulse digital subcarrier oscillator, whose output varies with the states of the three (base eight) or four (base sixteen) binary input signals. Any of these oscillators (analog or digital) may be commutated from channel to channel or one oscillator may be used for more than one channel. Since only one oscillator is pulsed at a time, adding additional oscillators does not materially affect the power drain.

The output of the system to the modulator is a square wave. Because of this and the inherent difficulty in employing phase-detection coherently when using frequency modulation, and the poor signal to noise considerations when using amplitude modulation, the rf carrier is phase modulated. Phase modulation has the advantage that the ratio of sideband power to carrier power may be controlled by changing the peak phase deviation. In order to provide adequate data information, for various satellite orbits, the system bandwidth (frequency range of oscillators), data rate (channel duration in time) and transmitter power are adjusted. For example, the PFM telemetry flown on Explorer XII had 5kc to 15kc oscillators and 10ms burst and blank tone durations. The highly eccentric orbit IMP series Explorer XVIII and Explorer XXI have oscillator frequency range of 200cps to 1kc and 320ms burst and blank tone durations.

Pulse Frequency Modulation was first flown on Vanguard III (1959). Since that time many other satellites have utilized PFM for their telemetry. Explorer VIII (1960), the Ionosphere Direct Measurement Satellite, and Explorer X (1961) which measured the interplanetary field both used PFM. Explorer XII (1961), Explorer XIV (1962) and Explorer XV (1962) which performed continuous measurements of energetic particles in the Van Allen belts all utilized PFM. The Interplanetary Monitoring Platforms, Explorers XVIII and XXI and the joint United Kingdom-United States satellites Ariel I and Ariel II have utilized this low-power lightweight telemetry.

REFERENCES

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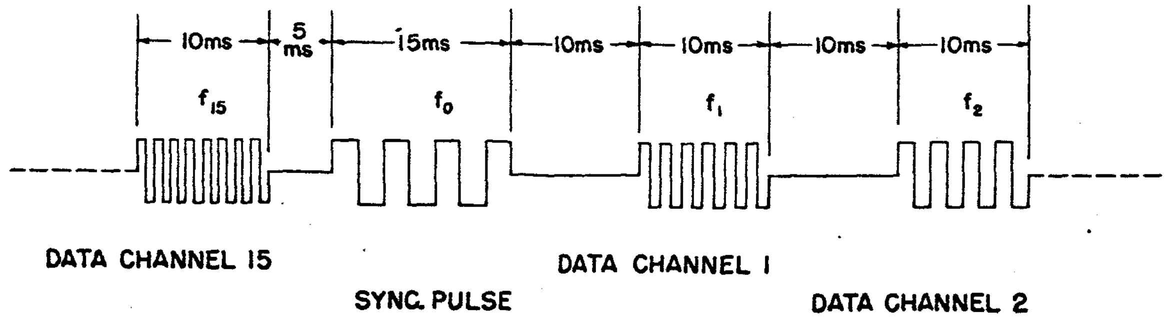
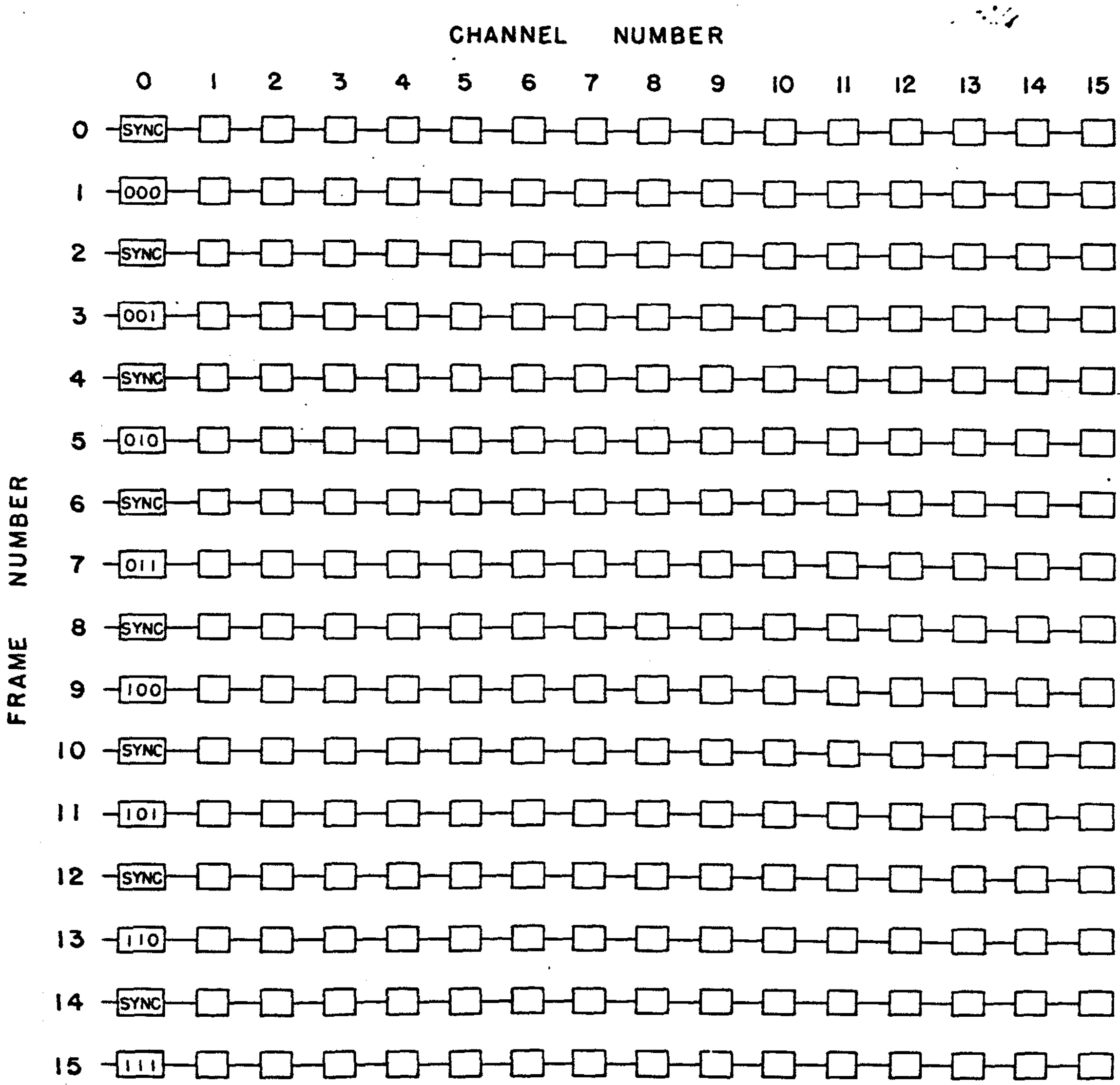

10ms
5 ms
15ms
10ms
10ms
10ms
10ms
f_{15}
f_0
f_1
f_2
DATA CHANNEL 15
SYNC. PULSE
DATA CHANNEL 1
DATA CHANNEL 2

(a)


CHANNEL NUMBER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
FRAME NUMBER
0 SYNC
1 000
2 SYNC
3 001
4 SYNC
5 010
6 SYNC
7 011
8 SYNC
9 100
10 SYNC
11 101
12 SYNC
13 110
14 SYNC
15 111

(b)